Rediset WMX®

Development of new warm mix technology offering enhanced asphalt properties

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Abstract

The road industry is today developing alongside advancements in technology, not only for economic reasons but also as a result of safety and environmental demand. Akzo Nobel has been working in the Asphalt Industry for many years, providing chemical solutions to paving problems, and this new warm mix technology was developed in response to these demands.

This paper details the research and testing carried out in independent and governmental laboratories and road trials in USA and Europe which resulted in the chemical warm mix additive – Rediset WMX®. The paper describes how it is possible to manufacture asphalt mixtures at lower temperatures while maintaining and even enhancing the high standard of paving materials expected in today's industry.

The Warm Mix additive was developed to be multi functional, providing the ability to reduce mixing and compaction temperatures by at least 30°C, widening the paving window, giving fewer VOC's (Volatile Organic Compounds) when mixing and paving, and ultimately reducing energy consumption resulting in lower CO_2 emissions. The original binder PG properties are also maintained. In addition, the product provides active and passive adhesion and improved cohesive strength and resistance to rutting resulting in more durable pavements that last longer leading to benefits in whole life costing.

Introduction to the new technology

In various forms, Warm Mix technology has been around for many years, but has failed to appeal to consumers. References to warm mix technology can be found dating back to the 1920's but it is only in recent years that the systems have reached full market introduction similar to what is see today. In recent years there has been renewed interest in the warm mix technology due to health and safety and environmental issues.

Warm Mix technology is available and Rediset WMX was found to offer a new solution to the warm mix challenge where warm mixing capability is combined with enhanced pavement properties.

Within the Hot Mix manufacturing process, a lot of energy is used to make the bitumen and heat the aggregate to the required temperatures. A large portion of the energy required to heat the aggregate goes into the drying process which is critical for durability. Typically, around
7 litres of fuel oil is used to heat one metric ton of aggregate up to 150°C (or 70kWh/ton) which is not only costly but also results in a large amount of CO_2 emissions.
For each litre of fuel oil that is burned, around 2.5 kg CO_2 are released into the atmosphere.
So for 100,000 ton mix this produces around 1,750 tons of CO_2 emissions.

Within the industry, 5 categories of Warm mix systems are on the market today

(1) Organic Additives
(2) Foaming Techniques
(3) Emulsion based techniques
(4) Low-viscosity vegetable based binders
(5) Chemical Additives

The products and their associated technologies are developed to assist the paving industry in many ways. Some are the following: -

Lower overall energy consumption
Reduce energy costs
Reduce green house gases
Reduce VOC's which workers are exposed to
Reduce VOC's which contribute to photochemical smog
Minimise binder hardening
Maintain or improve compaction characteristics
Help to extend the paving season

The Goal of the system

Rediset WMX® is a chemical additive product which was developed to fulfil several demands from the matured warm mix market.
Some of these goals are as follows: -

- *Develop a multipurpose system which is versatile, working on a wide spectrum of bitumen, aggregate and mixes.*
- *Modifying the bitumen whilst maintaining or improving the binder properties at pavement temperatures.*
- *Allowing verification of the Performance Grading of the modified binder (PG)*
- *Avoid the introduction of water which could have a negative effect on the adhesive and cohesive properties of the binder.*
- *Improve the moisture resistance of the asphalt mix and so avoid the need for separate addition of cement, lime and other adhesion promoter.*

This paper describes the laboratory and field evaluation of the new system. The data and conclusions from several laboratory and field trials are summarised to demonstrate the benefits of the system.

Product concept

Firstly it is believed that the surface active formulation of the Rediset will allow the bitumen to disperse and "wet" the aggregate surface as if the surface tension is reduced.

a) Providing a dispersion effect by lowering the viscosity of the bitumen filler mastic because the filler has a more hydrophobic surface due to surfactant adsorption.
b) The surfactant in the bitumen makes it easier to coat the aggregates and therefore making it easier to compact.

While this is happening, the part of the product which is the nitrogen containing surfactant, will anchor the hydrophobic tail into the bitumen and the hydrophilic amine group will adsorb on the aggregate surface. This drives away any moisture present giving a strong linkage between the bitumen and aggregate preventing water from entering this interface.

c) Lowering the contact angle of the bitumen allowing coating of the aggregate even in the presence of water.

Once the Asphalt mixture is made, the passive adhesion characteristics of the product can start, sharing hydrogen between the amine head and the aggregate surface. This chemical bond will survive throughout the pavements design life and also continue to function in future recycling applications.

d) Promoting chemical bonding of bitumen and aggregate (amine groups bond to siliceous surfaces and the hydrocarbon chains becomes part of the bitumen. So it acts as a bridge that holds bitumen and aggregate together)

How the product is used

Rediset WMX is a flaked/crumbed product which is added to the bitumen's storage tank or into the flowing bitumen line before production of the asphalt mixture. Depending on desired performance, between 1 and 2% is added (as a percent of the bitumen content) equating to approximately 0.5 to 1kg of product is needed for 1 ton of asphalt mixture.
The product has a melting point of 110°C therefore, during agitation it will disperse quickly in bitumen at 150°C.
The laboratory mix design process and final mix design remain the same, with the only exception that additives like cement or lime and adhesion promoters are not needed as the product has built in provisions for active and passive adhesion enhancement.
Asphalt manufacturing is performed as normal with the great exception of lowering the aggregate temperature for asphalt production. Alternatively, the mixing temperature can be kept as normal which then allows for; a wider delivery radius of the mix, longer storage times and also allows paving and compaction at lower ambient temperatures.
So far it has been tested at a 30°C reduction in asphalt mix temperatures (160°C down to 130°C) , and laboratory studies shown that further reductions should be possible in full scale production.

Methods of evaluation

In the development of the Rediset WMX warm mix additive, Asphalt institutes and contractors in the USA and Europe have performed laboratory and field testing to verify and trial the function of the additive. A selection of results from those tests and trials are detailed in the following section.
There are several evaluation methods which have been used to verify the performance of the product in comparison to conventional Asphalt manufacturing methods.
This is shown in 3 categories: -

1. Tests for bitumen modified with the Rediset WMX additive
2. Laboratory and field compaction testing
3. Tests for stripping or moisture resistance (Wheel Tracking, Static Immersion, TSR)

Tests for bitumen modified with the Rediset WMX additive

(1.1) PG grading and viscosity of modified and un-modified bitumen

Performance Grading was developed in the USA to assist in the classification of the right binder for the right climate. The PG is a description of a given climate and the bitumen must perform to given parameters within that climate classification, using rheological tests on aged and un-aged binder. Changes to the bitumen properties by the addition of the additive will be observed through this classification.

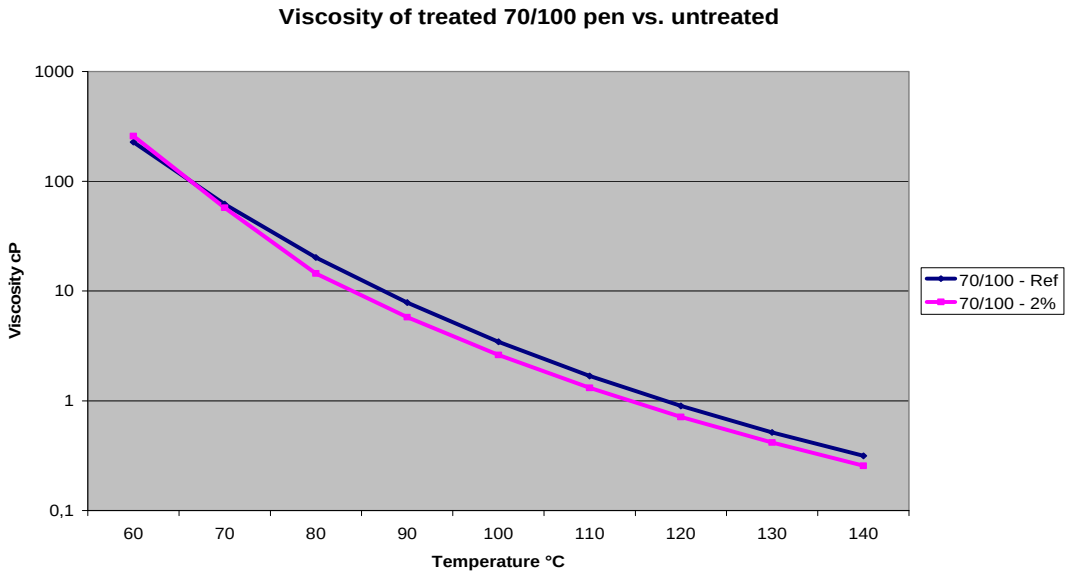
The *table (1.1)* below shows a summary of the results of PG testing and viscosity on a PMB with and without the warm mix additive.

Binder treatment	Test	Spec.	Pg 64-22	PG 64-22 + 2% WMX	PG 76-22 (blue line)	PG 76-22 + 2% WMX
Un-aged	G*/Sin d (kPa) @ 76°C	> 1.0	1,34	1,21	1,17	1,03
RTFOT residue (a)	RTFOT G*/Sin d (kPa) @ 76°C	> 2.20	3,47	3,31	2,49	2,25
PAV residue	BBR Creep Stiffness, S (MPa), @ -12°C	< 300	154	161	185	140
PAV residue	BBR, Slope m-Value @ -12°C	> 0.300	0,333	0,319	0,316	0,344
Un-aged	Binder Phase Angle @ 76°C in degrees	*	85,6	86,2	73,8	72,0
	Result		PG 66-25	PG 65-25	PG 76-22	PG 76-22

**Lower phase angle = more elastic binder.*
(a) The aging was done at the same temperature (163°C) for these samples - no allowance was made for the typical lower mix temperatures of the warm mix product.

Table (1.1) PG data comparison
Dongre Laboratory Services, Inc. Fairfax, Virginia, USA

Graph (1) shows viscosity curves for Rediset WMX treated and untreated bitumen



Graph (1): Viscosity curve of 70/100 pen (blue) and 70/100 pen + Rediset WMX (red)
Nynas Bitumen AB. Nynashamn, Sweden

(1.2) Bitumen properties before and after Asphalt Manufacturing process

The properties of treated and un-treated bitumen were examined before and after mixing. Penetration and Ring & Ball testes were performed on normal and Rediset WMX treated bitumen before mixing and after mixing via recovered binder from the road pavement.
In reducing the manufacturing temperature and incorporating the Rediset WMX into the binder, we see almost no change in bitumen properties after the manufacturing process whereas there is a significant difference in penetration (84 to 35) when mixing without Rediset WMX.

	70/100 pen	70/100 pen + 2% WMX	70/100 pen	70/100 pen + 2% WMX
penetration (mm)	84	75	35	79
R&B (°C)	45	47	53	46
	Before mixing		After mixing	

Table (1.2) Penetration + Ring & Ball data - Tullamore contract. Irish Tar and Bitumen. Dublin, Ireland.

(1.3) Comment and conclusions on the bitumen properties

When data from several bitumens is analysed, the following conclusions can be made: -

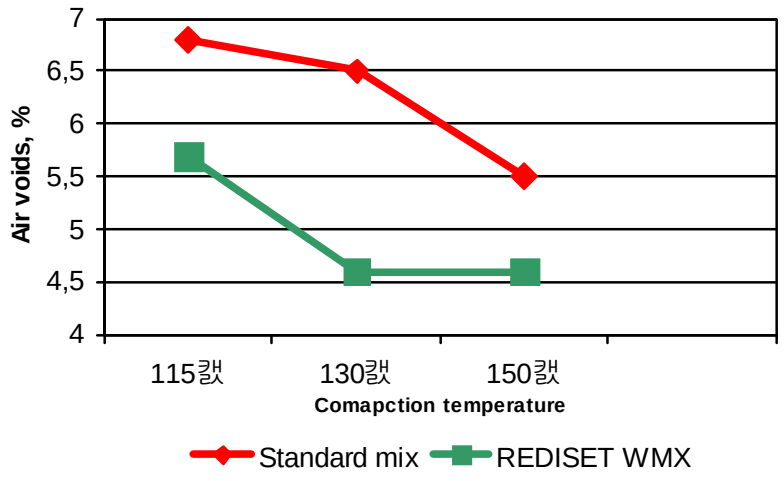
- Graph (1) show viscosity of the treated binder is not significantly different to the untreated. The difference in viscosity is not an explanation of the warm mix effect.
- Table (1.1)
  - G* viscosity tests were performed on treated binder after aging in the RTFOT *(Rolling Thin Film Oven Test)* and PAV *(Pressure Aging Vessel)* and they gave lower results compared to untreated binder samples which suggests some anti-aging effect of the warm mix additive.
  - Generally the high temperature grade is not affected by the use of the additive.
  - The RTFOT data shows an anti-aging effect, where less binder hardening is seen from the treated sample opposed to the untreated bitumen samples even if the treated binder is a little stiffer.
  - Generally the low temperature grade is not affected by the additive, but in some cases lower (s) and higher (m) values are seen which relates to better low temperature properties.
  - The additive did not have a negative affect on the benefits of polymer modification as illustrated by the phase angle data.
- Table (1.2) shows when Rediset WMX is used in combination with reduced mixing temperature the penetration value still maintain its properties whereas the regular mix will get a significantly reduced penetration value i.e. substantially harder bitumen. The same trend shows the R&B values. The mix with Rediset WMX and reduced temp keeps the same value whereas the regular mix will get an increased R&B value after mixing. This clearly shows that the combination of Rediset WMX and reduced temperature will prevent the bitumen from oxidation in the manufacturing process.

Laboratory and field compaction testing

An Asphalt mixture must have workability to be placed, thus the mixture must be designed correctly to have compactability in order to achieve the required density which will ensure the durability of the pavement.
Some mixtures have workability but do not have compactability; so you can place a colder mixture but you can not achieve the target compaction density which could result in reduced durability.
The warm mix additive should allow a cooler mixture to be both workable and compactable.

(2.1) Laboratory studies

The densification summary is shown in G*raph 2.1 (Laboratory studies by NCAT - National Centre Asphalt Technology in the USA.)*
From the data it can be seen that when the Rediset WMX is introduced into the Asphalt mix the Air Void content is much lower at all 3 compaction temperatures. This offers a possibility to reduce mixing/paving/compaction temperatures by at least 30°C and obtain the same void content.



Graph (2.1): Compactability summary
National Centre for Asphalt Technology, Auburn, AL, USA

(2.2) Field trial in Chico, California USA

Results from a field trial in Chico, California USA are shown in *Table (2.1)*
Baldwin Contracting Company, California, carried out paving trial where Rediset WMX was compared to a normal grade binder. 230 tons of each product was mixed and paved at 3 different temperatures. Samples were taken from the paving process and cores were drilled from the final pavement. Performance testing and evaluation was performed using ASTM D2726 and CTTM CT308A test methods.

It was found that mixtures which contained the Rediset WMX additive achieved a higher density with a temperature reduction of > 30°C, while there was no negative influence observed from the PG64-10 binder and fewer roller passes were needed.
Unlike the mixture prepared from untreated binder, no “tender” zones were seen.

Type of mix (PG64-10)	% Relative compaction			
	CT 308A Method		ASTM D2726 Method	
	Core Density (bulk)	%RC Rice	Core Density (bulk)	%RC Rice
115°C Mix (Ave.) 2% Rediset WMX	2.319	91.9%	2.327	92.2%
130°C Mix (Ave.) 2% Rediset WMX	2.329	92.3%	2.339	92.7%
150°C Mix (Ave.) Control mix	2.275	90.2%	2.286	90.6%

Table (2.2.1): Onsite measurements Chico, California. Baldwin Contracting Company Inc. Chico CA, USA

Confirmation during the field trial in Chico, California, confirms the laboratory results.

Type of mix	Bulk density Mg/m^3
150°C standard mix	2.286
130°C REDISET WMX	2.339
115°C REDISET WMX	2.327

Table (2.2.2): Onsite Nuclear Density measurements Baldwin Contracting Company Inc. Chico CA, USA

(2.3) Other field trial in USA and Europe

Hot-mix formulations containing a high percentage of R.A.P. tend to be much stiffer and more difficult to work with than standard mixes. Field trials with the Rediset WMX and RAP proved successful at lower mixing and compaction temperatures.
The compaction data from the other field trial confirmed that target densities could be achieved from the mixes prepared from the treated bitumen.

Tests for stripping and moisture resistance

(3.1) Adhesion testing via Static immersion

One of the targets was to improve the moisture resistance of the mixture as this is particularly important in warm mixes because the aggregate may not be fully dried at lower mixing temperatures. This test procedure allows investigation into the ability of the bitumen/aggregate mixtures to withstand accelerated stripping by testing the mixture above the bitumen's softening point.
This elevated temperature will force the surface bitumen/aggregate bond to survive via chemical function alone.

Various Warm Mix Additive dosages, storage times in hot bitumen and bitumen acid contents were tested to establish an expected adhesive enhancement from the usage of the product.
From the data shown in *graph (3.1)*, the additive has raised adhesion values from 20% to 100% coating when directly used in the process. If long term bitumen storage is needed, adhesion is remaining at 100% with Low naphthenic bitumen and 80% adhesion in High naphthenic if stored in bitumen for 3 days.

Test Method for Coating and Stripping of Bitumen-Aggregate Mixtures
Akzo Nobel, Sweden - AA002, based on ASTM D1664-80(1985)
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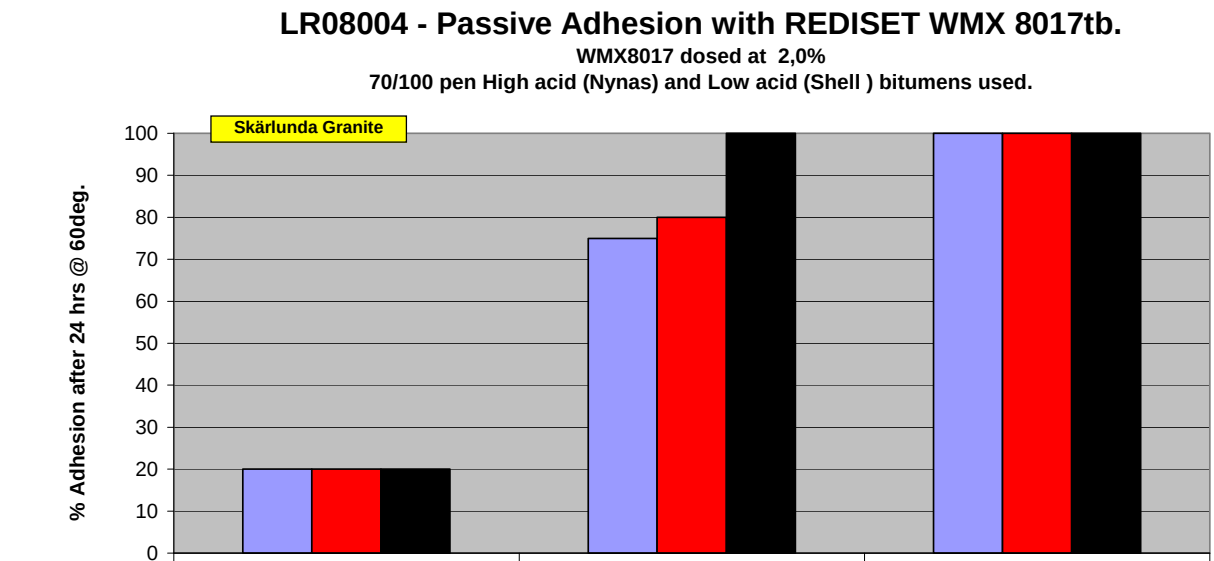


	control	8017tb HA 2,0%	8017tb LA 2,0%
7 day HTST	20	75	100
3 day HTST	20	80	100
Fresh Bitumen.	20	100	100

Adhesion readings after 24hrs @ 60°C
HTST = High temperature storage tests at 160°C

Graph (3.1): Static immersion tests showing passive adhesion.
Akzo Nobel Surface Chemistry AB, Stenungsund, Sweden

(3.2) Indirect tensile strength testing – Adhesion value with Freeze Thaw.

Asphalt material manufactured at low temperatures could have moisture trapped within the mixture and this will cause the de-bonding of the bitumen from the stone/aggregate surface.
To verify the performance, Tensile Strength Ratio was performed at NCAT and PaveTex.
Using *ASTM D 4867 Effect of Moisture on Asphalt Concrete Paving Mixtures including freeze thaw cycle*, the warm mix additive was evaluated along side standard mixtures. Results below in *table 3.2* are from samples taken on site in the California field trials.

The mixes are compacted to a target air void in a gyratory compactor then one set is kept dry and the other set is conditioned. The conditioned set is subjected to a freeze thaw cycle followed by soaking in warm-water for a certain number of hours. Then the indirect tensile strength is determined and the ratio of the wet (conditioned) strength to the dry strength gives the Tensile Strength. Higher the number better is the moisture resistance properties. Generally 80% and above TSR value is accepted.

Mixture	Mix temperature °C	Average strength Wet (PSI)	Average strength Dry (PSI)	TSR (%)
Asphalt with 2% Rediset WMX	132	100.7	124.7	80
	137	100.2	114.9	87
Control	156	55.2	122.8	45

Table (3.2): TSR results of field samples.
PaveTex Engineering and Testing, Inc, Austin Texas, USA

The main observation was that the control mix had a low TSR (0.5 or so) whereas the mixes modified with Rediset WMX significantly improved the TSR value.

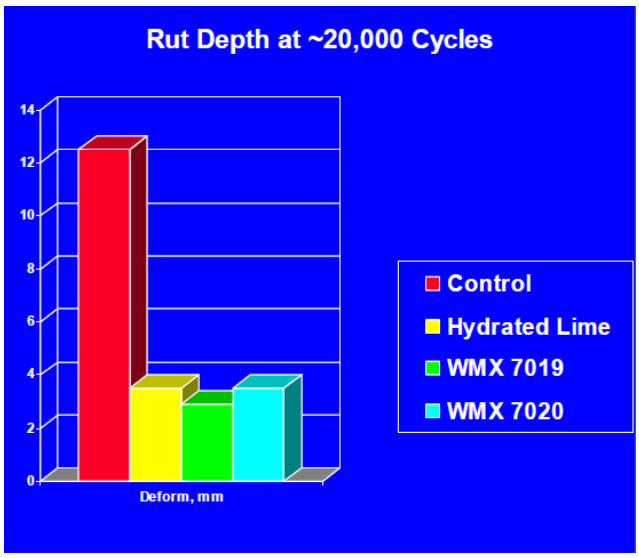
(3.3) Hamburg Wheel Tracking Test

The Hamburg Wheel Tracking test is one of the most severe tests for stripping. The compacted slabs are kept under water and water temperature is maintained at 50°C. A steel wheel roller is run back and forth on the compacted specimen. In the Texas version of the Wheel tracking test (depending on the type of mix) the mix should withstand certain number of cycles (depending on the mixture) and the rut depth should be below 12.5 mm.
In this particular test *Table and Graph 3.3* the mix has to go through 20,000 cycles. The control mix failed to go past the 20,000 cycles whereas the mixes modified with hydrated lime and Rediset at 20,000 cycles had a rut depth of only 3.50 and 2.93 mm respectively. With the mix modified with the Rediset the test was taken up to 30,000 cycles and still the rut depth is only 3.41 mm. The results show that the Rediset significantly improves the moisture resistance properties of the mix compared to the control and give similar or better results compared to the mix modified with hydrated lime.

Material Mix Additive	Dosage KG/ton mix	Cycles	Deformation
Control	0	18,177	12.50
Hydrated Lime	20 kg	20,000	3.50
REDISET WMX	1 kg	20,000 25,000 30,000	2.93 3.19 3.41

Note: Hydrated lime was used for Strength comparison purposes and not as a warm mix alternative.

Table (3.3) Hamburg Wheel Track test.
PaveTex Engineering and Testing, Inc, Austin Texas, USA



Graph (3.3): Hamburg Wheel Track test results.
PaveTex Engineering and Testing, Inc, Austin Texas, USA

Summary

Rediset WMX® offers reduced VOC's during manufacturing and paving of Asphalt mixtures due to the ability to manufacture at lower temperatures, while maintaining the mixtures compatibility and improving the moisture resistance properties which help to extend the pavements operational life time.

When laboratory and field data from various tests was analysed, it was found that Asphalt containing the WMX additive was meeting performance requirements for Relative compaction, TSR, Adhesion Value, and deformation. In common with other warm mix systems the lower mix temperature is expected to result in energy saving and lower CO_2 emissions.

The properties of the bitumen, as determined by the PG grading are not adversely affected, and more importantly can be verified in the same manner as untreated binders.

Mixing and storage of the product can also be manipulated to the customers' preferences.
There are 2 manufacturing options within the system: -

(1) Produce at lower temperatures, achieving the desired compaction and material performance within the normal delivery range, or
(2) Manufacturing at normal temperatures which enable longer storage time and delivery radius due to the mixtures low temperature compactability.

References

(1) Asphalt Manufacturing in Sweden, Energy calculations courtesy of
Skanska Sverige AB, Krister Persson.

(2) Norwegian Asphalt Institute. European Asphalt Contractors view on Warm Mix technology in the future and Status Report - Warm Asphalt Mixtures -Egbert Beuving, European Asphalt pavement Association.

(3) Warm-Mix Asphalt: Report No.FHWA-PL-08-007
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(4) The Classification of Bitumens and Polymer Modified Bitumens within the SHRP Performance Grade System. Carswell, J.; Claxton, M.J.; and Green, P.J. 2nd Eurasphalt and Eurobitumen congress, Barcelona 2000 – Proc.0162.uk